

# **Calorimetry Studies for Muon Collider using ILCroot**

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# Outline

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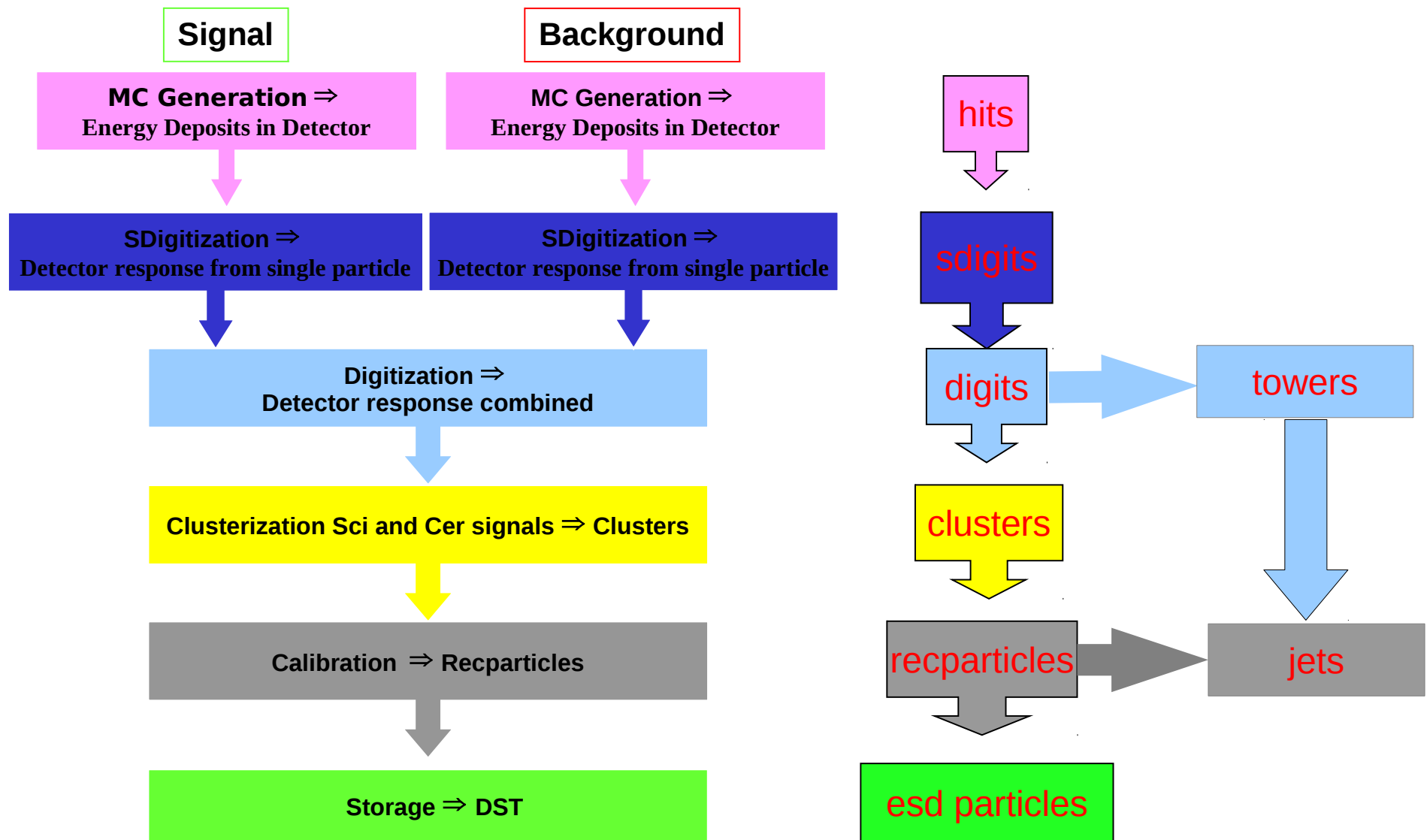
- **Detector baseline**
- **MARS event generator**
- **Background studies in the calorimeter**
- **Physics and background merging issues**
- **Conclusions**

# ILCroot: **root** Infrastructure for **L**arge **C**ollider

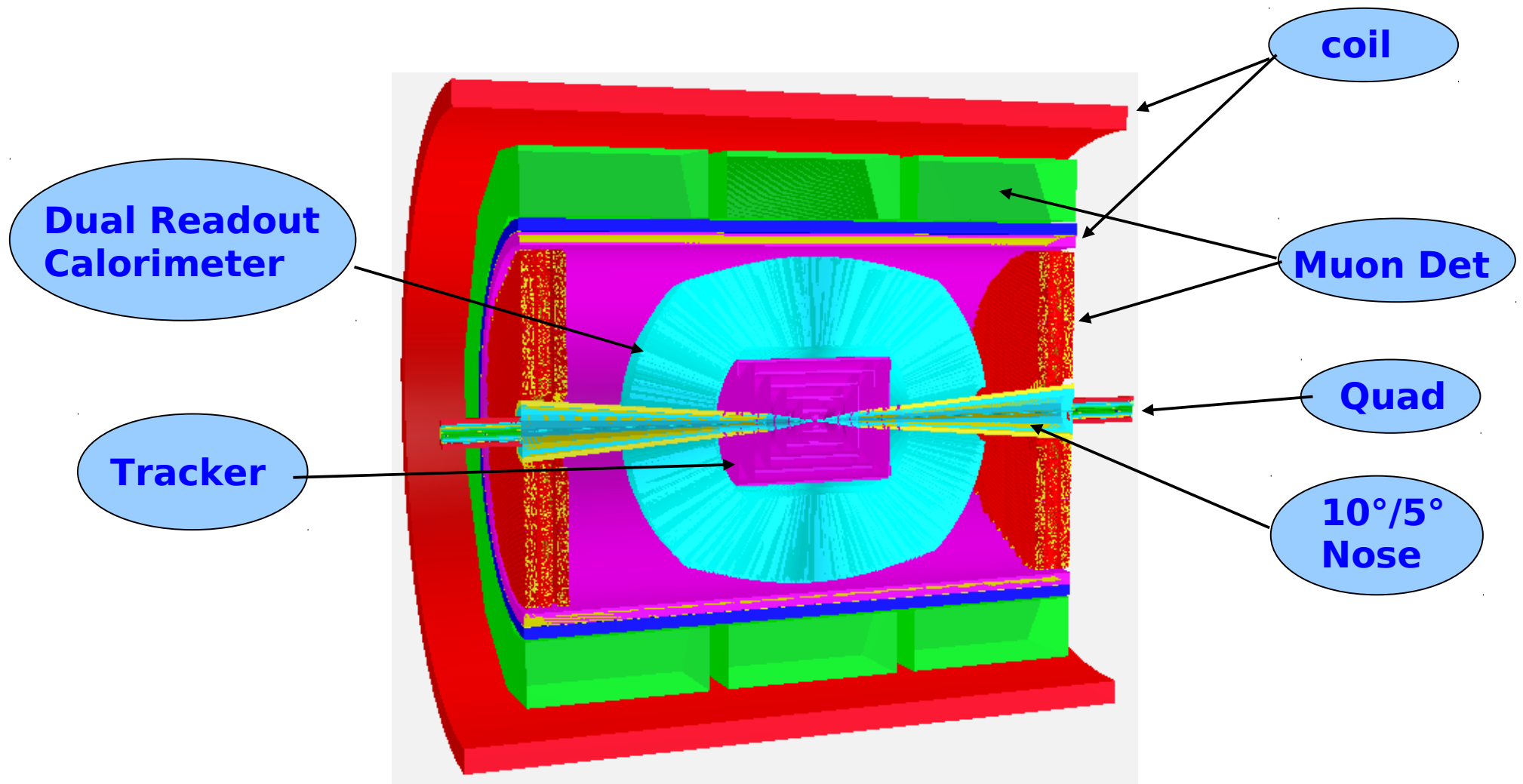
- Software architecture based on ROOT, VMC & Aliroot
- Uses ROOT as infrastructure
  - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
  - Extremely large community of users/developers
- Include an interface to read MARS output to handle the MuonCollider background
- **Single framework**, from generation to reconstruction through simulation. Don't forget analysis!!!
- **It is Publicly available at FNAL on ILC SIM since 2006**

**All the studies presented are performed by ILCRoot**

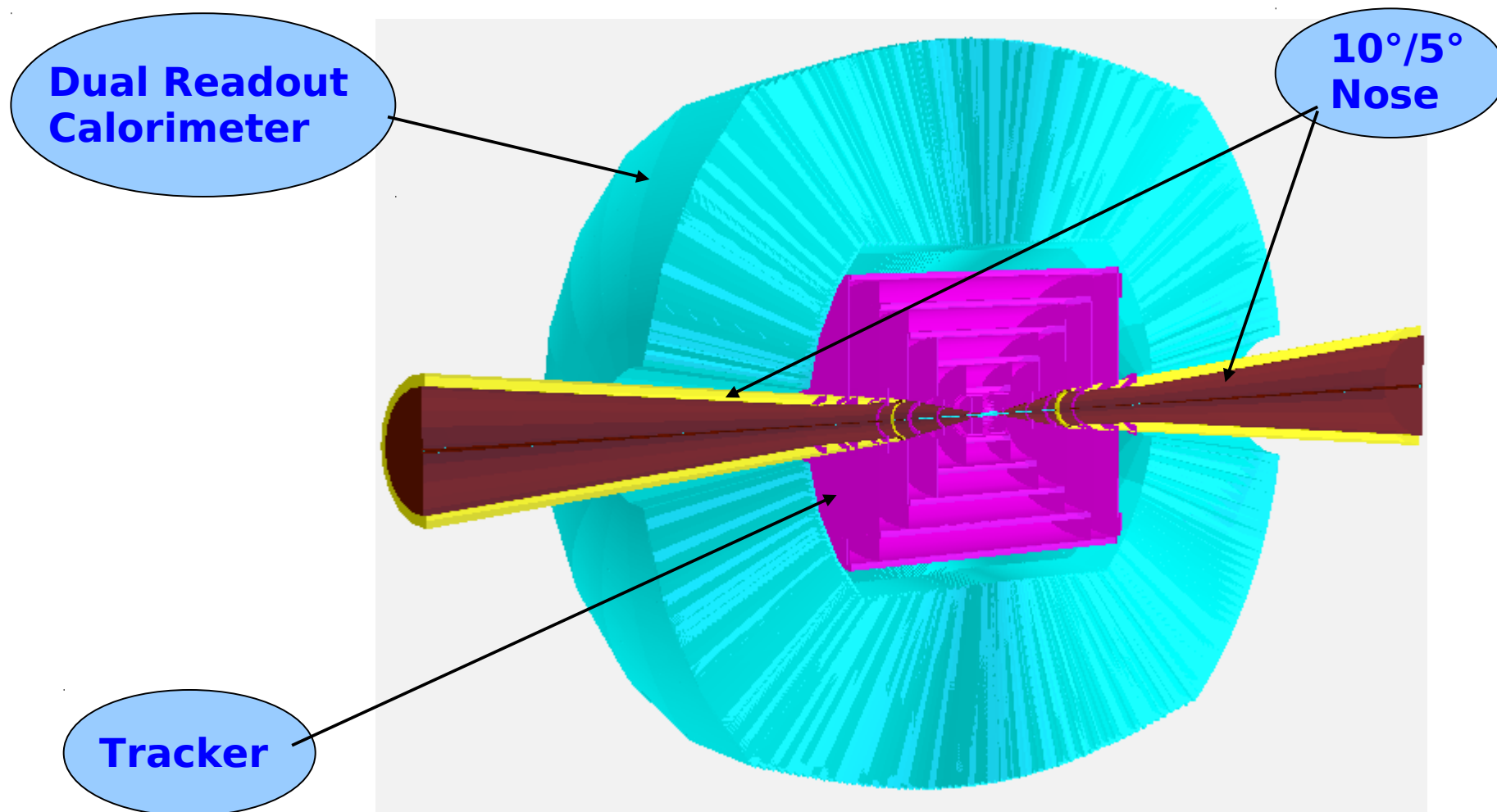
# Simulation steps in ILCroot: Calorimeter system



# Detector baseline



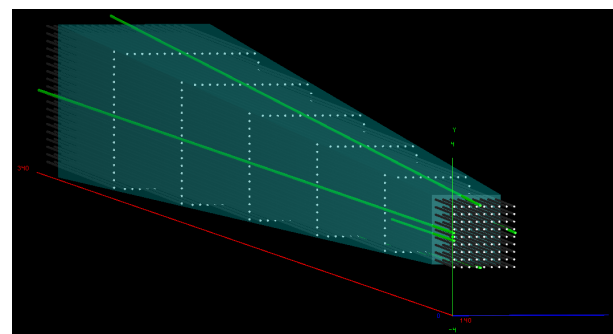
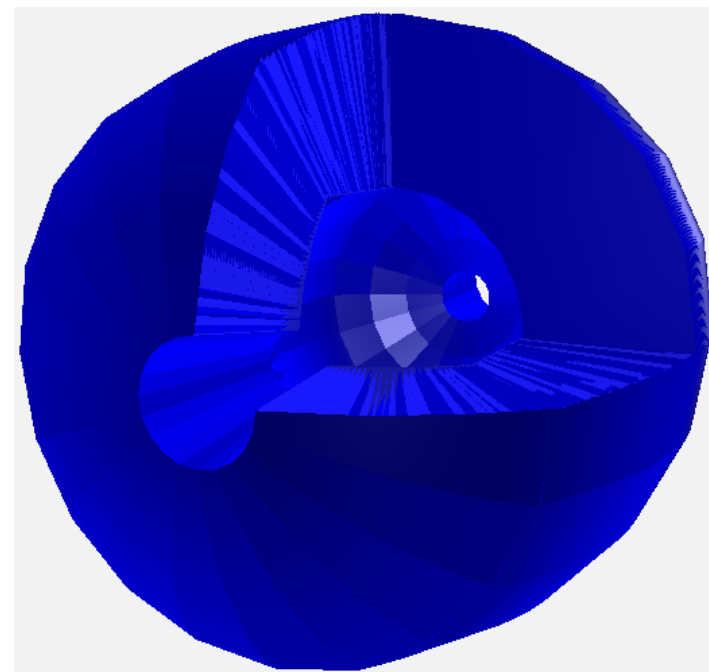
# Detector baseline zoom



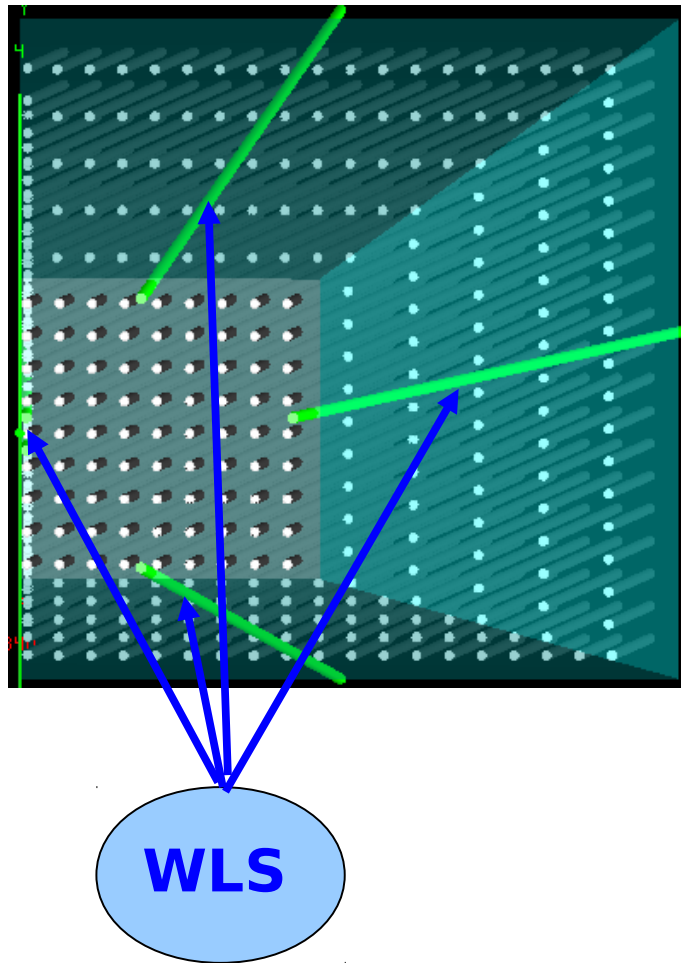
# Dual-readout Calorimeter for $\mu$ Collider studies

- Lead glass + scintillating fibers
- $\sim 1.4^\circ$  tower aperture angle
- 180 cm depth
- $\sim 7.5 \lambda_{\text{int}}$  depth
- $>100 X_0$  depth
- Fully projective geometry
- Azimuth coverage down to  $\sim 8.4^\circ$  (Nozzle)
- Barrel: 16384 towers
- Endcaps: 7222 towers

**ADRIANO** Calorimeter (FNAL-INFN Collaboration) is used for the studies presented here



# Detector baseline for these studies



- **WLS's collect Cerenkov photons generated in lead glass (front and back readout)**
- **Generate and transport scintillating photons (front and back readout for fibers in the core of the tower; only back readout for the other fibers)**
- **Simulation include:**
  - **SiPM with ENF=1.016**
  - **Fiber non-uniformity response = 0.8% (scaled from CHORUS)**
  - **Threshold = 3 p.e. (SiPM dark current < 50 kHz)**
  - **ADC with 14 bits**
  - **Gaussian noise with  $\sigma = 1$  p.e.**

**PRESENTLY IN A TEST-BEAM BY T1015 COLLABORATION**

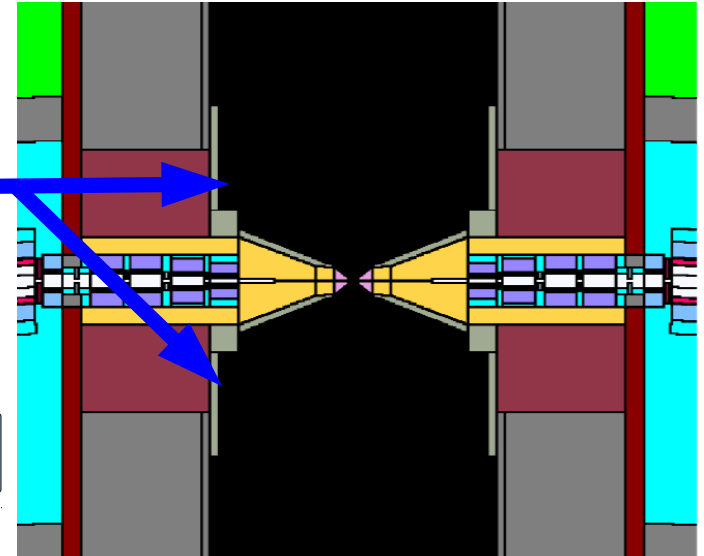


# Simulating MARS generated event with ILCroot

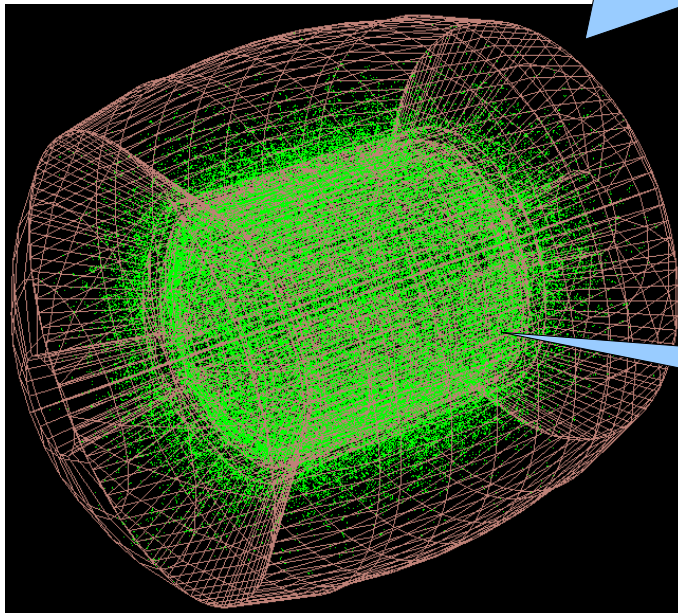
- **Simulated 1 MARS event**
  - **Origin of the particles: MDI surface**
  - **Background particles for  $\mu^+$  and  $\mu^-$  within 25 m and beyond 25 m**
  - **Particle in a MARS event  $\sim 10^8$ , almost all originated within 25 m**
    - (See S. Striganov talk for more details)
  - **Particles from within 25 m have weight  $\sim 20$** 
    - **These particles are split using azimuthal symmetry**
  - **Particles from beyond 25 m have weight  $\ll 1$** 
    - **Pick up randomly these particle, taking care the integral weight is the same**
    - **This have been done 10 times, then the average signal have been used**
- **Results presented use only background within 25m**

# Some simulation details

- Muon Collider particles background provided by MARS15 at the MDI surface (black hole surface)
- Particles (Physics and background) are tracked in the detector using Geant4



Event display only 4% of the full background

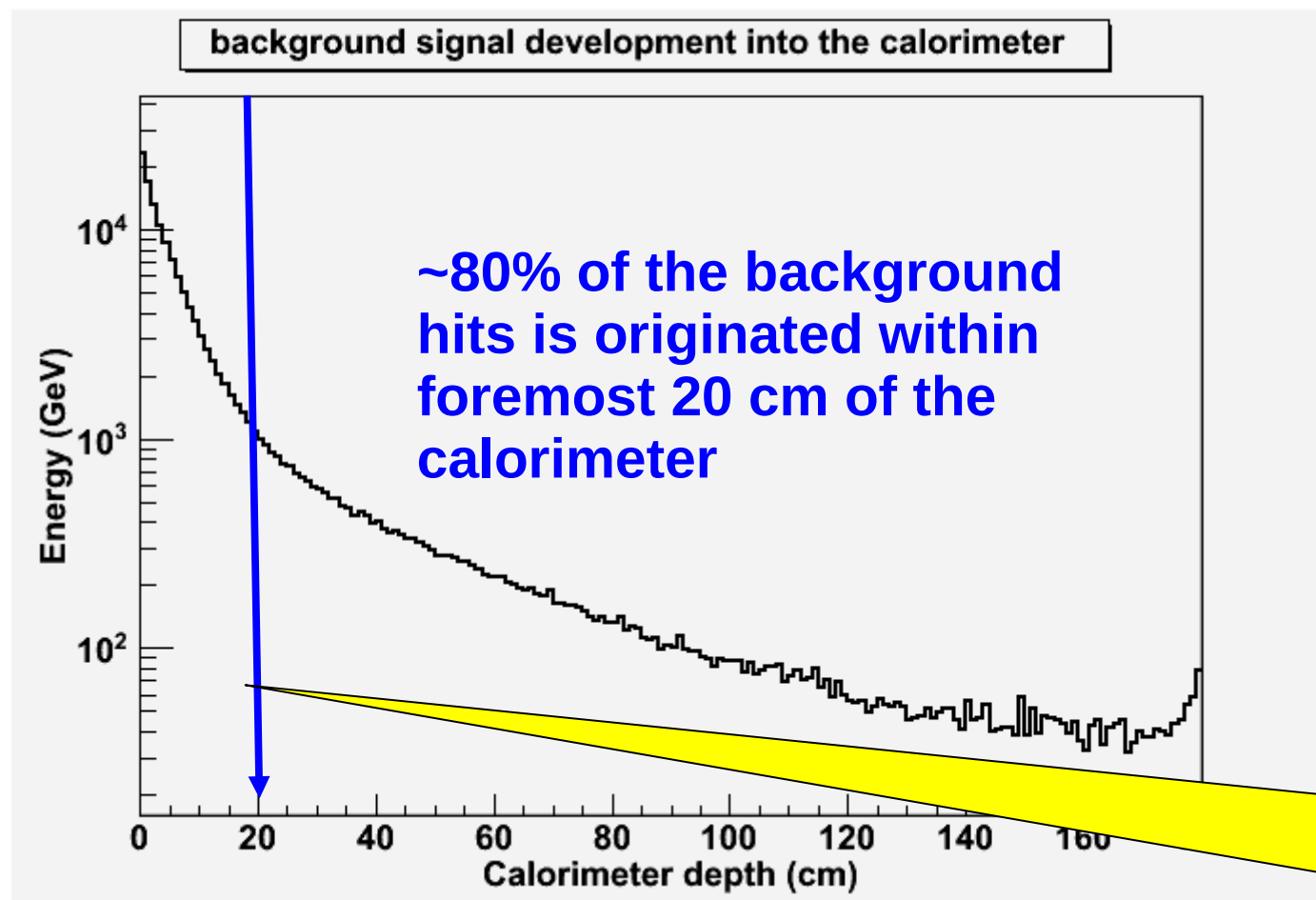


- Dual Readout calorimeter provide the measurement of the energy

Hits in the calorimeter

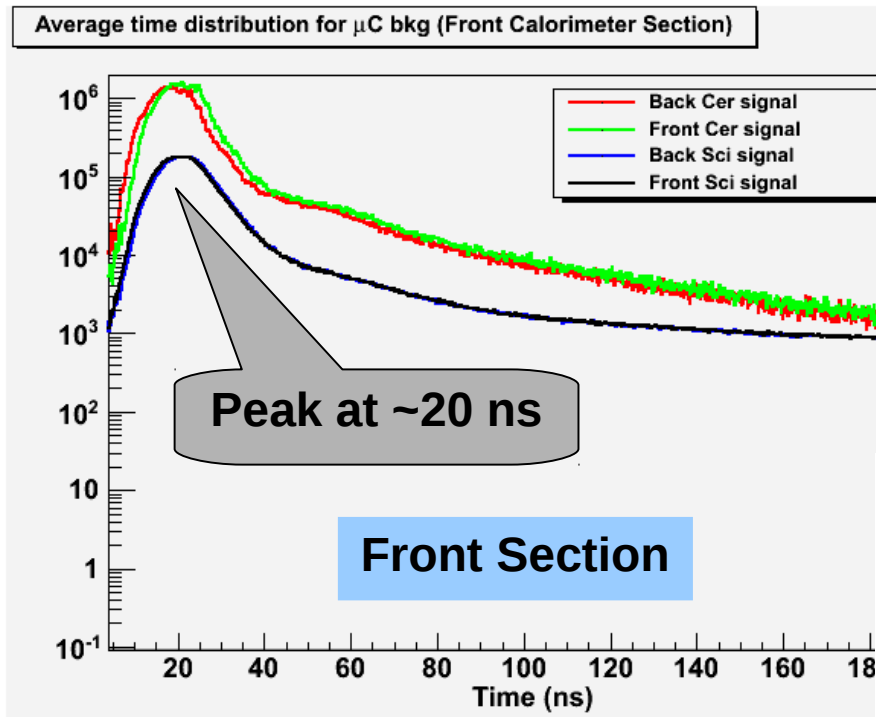
# Timing and space distributions of one background event into the calorimeter

# Longitudinal energy deposition in Dual-Readout calorimeter produced by 1 background event



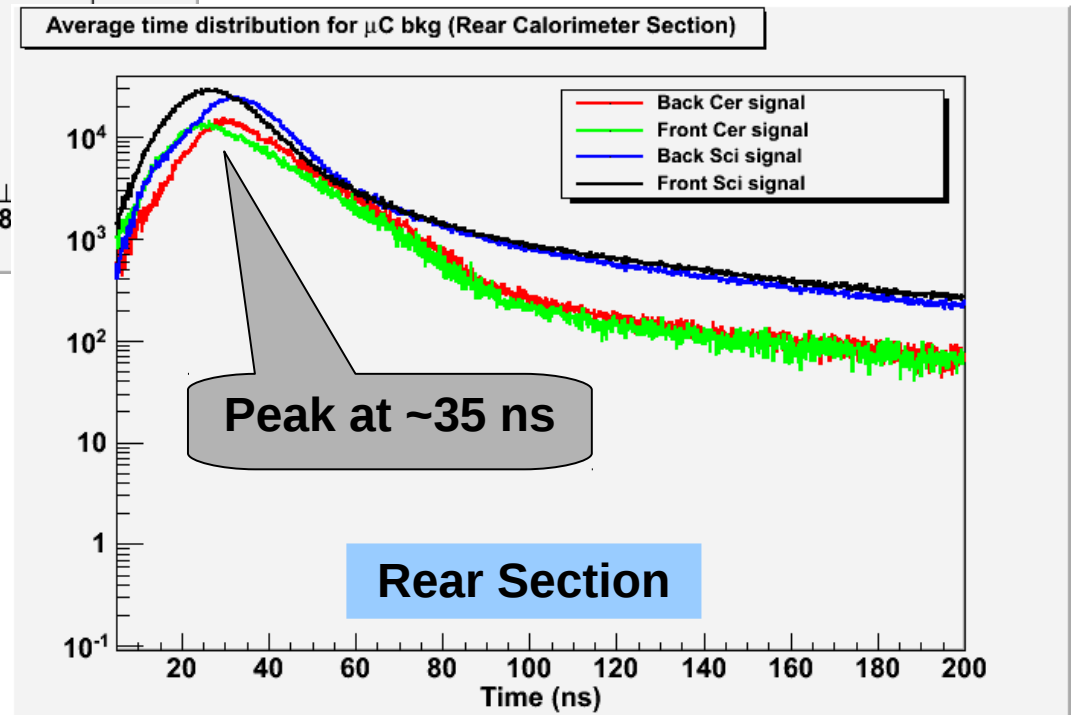
Longitudinal segmentation of the calorimeter could be beneficial

# Time distribution of the MuonCollider background



Calorimeter is now split in a forward (20cm) and rear (160 cm) section

Light propagation in fibers and lead glass is implemented in ILCroot

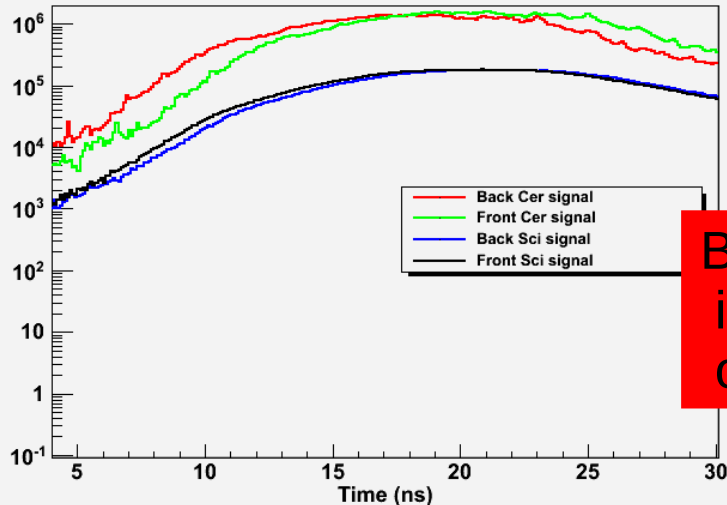


# Time distribution of the MuonCollider background and particles from IP

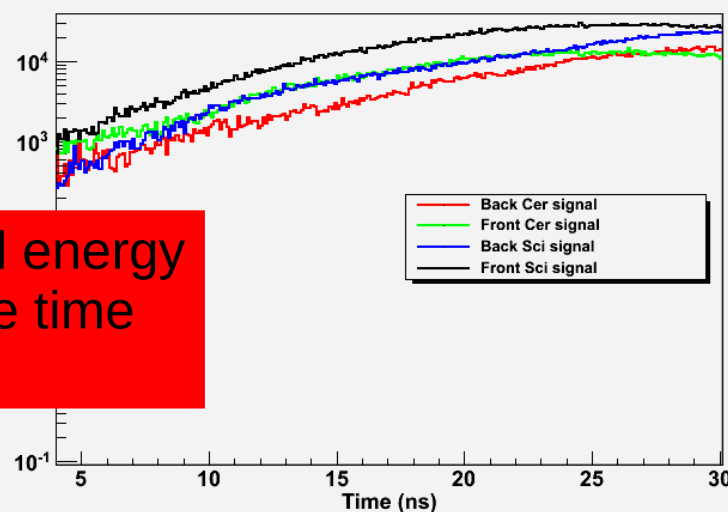
Front Section

Rear Section

Average time distribution for  $\mu C$  bkg (Front Calorimeter Section)

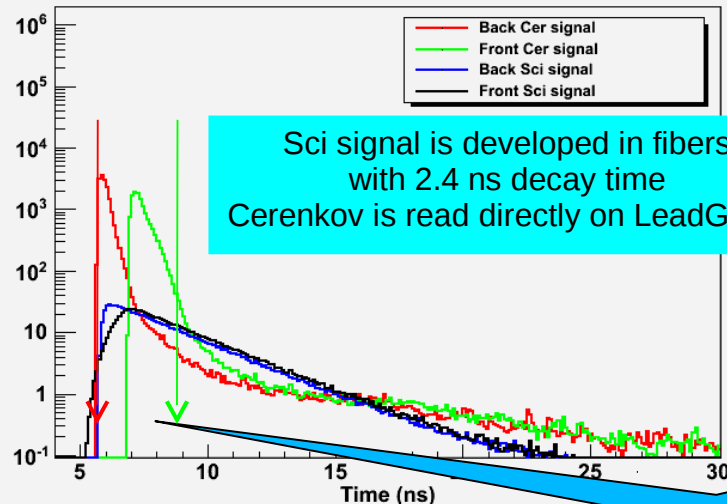


Average time distribution for  $\mu C$  bkg (Rear Calorimeter Section)



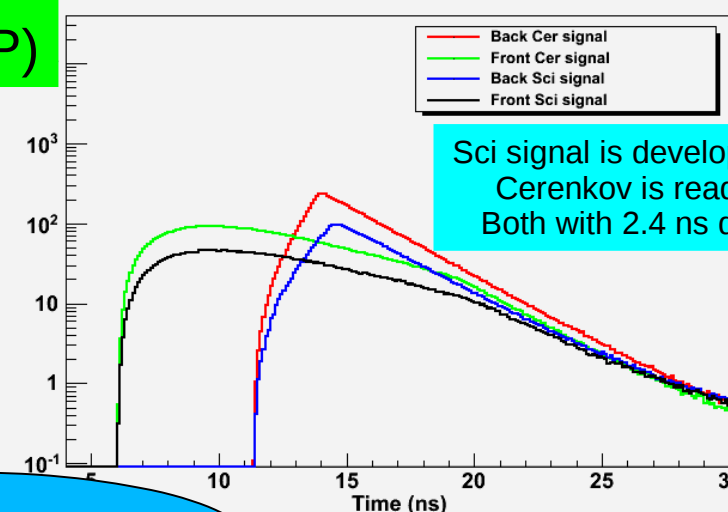
Background energy  
in the range time  
of Physics

Average time distribution for  $\pi^-$  @ 40 GeV (Front Calorimeter Section)



Sci signal is developed in fibers  
with 2.4 ns decay time  
Cerenkov is read directly on LeadGlass

Average time distribution for  $\pi^-$  @ 40 GeV (Rear Calorimeter Section)



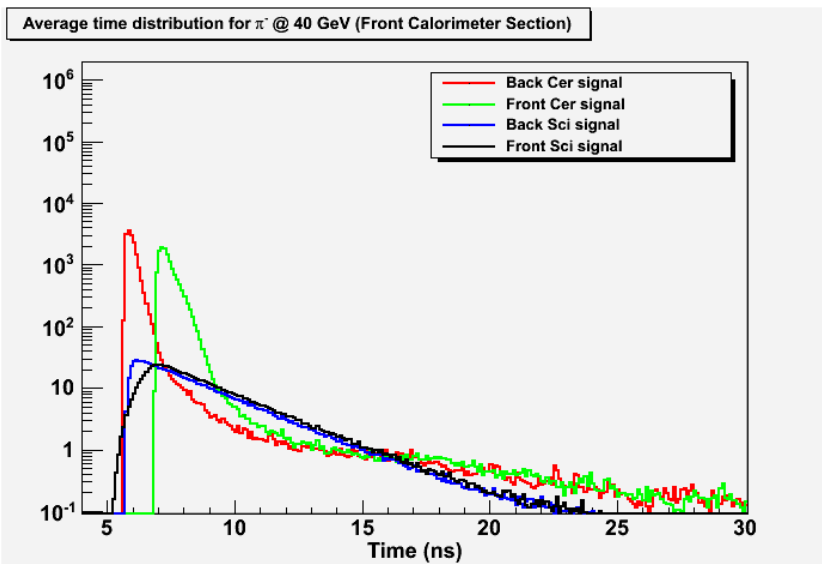
Sci signal is developed in fibers  
Cerenkov is read by WLS  
Both with 2.4 ns decay time

Physics  
( $\pi^-$  from IP)

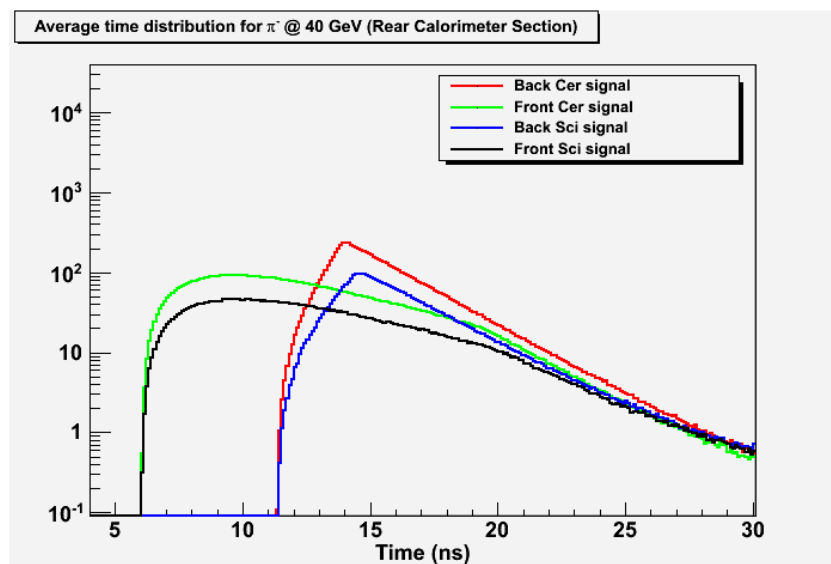
Most of physics occur  
within 7 and 10 ns

# Time distribution of the MuonCollider background and particles from IP

Front Section



Rear Section



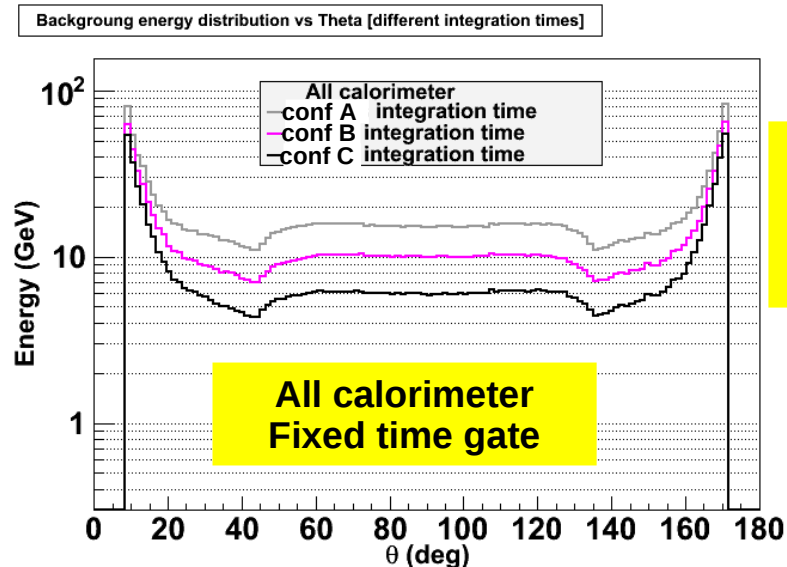
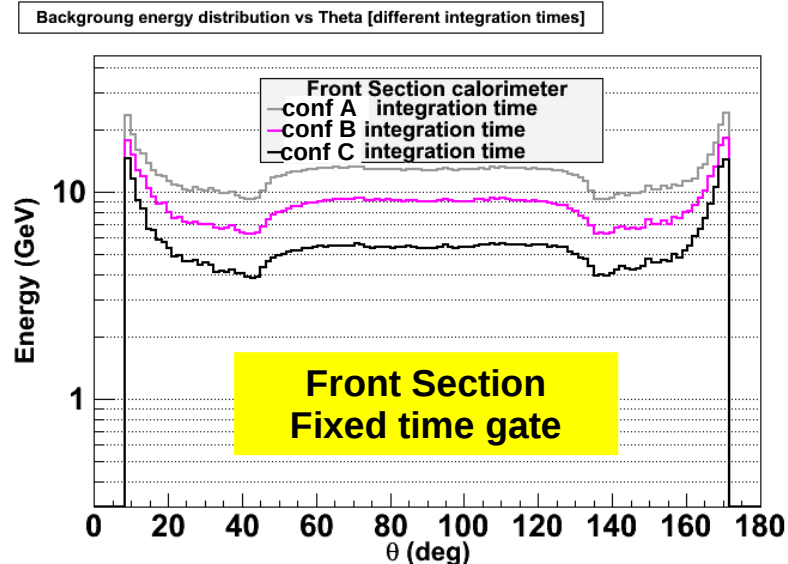
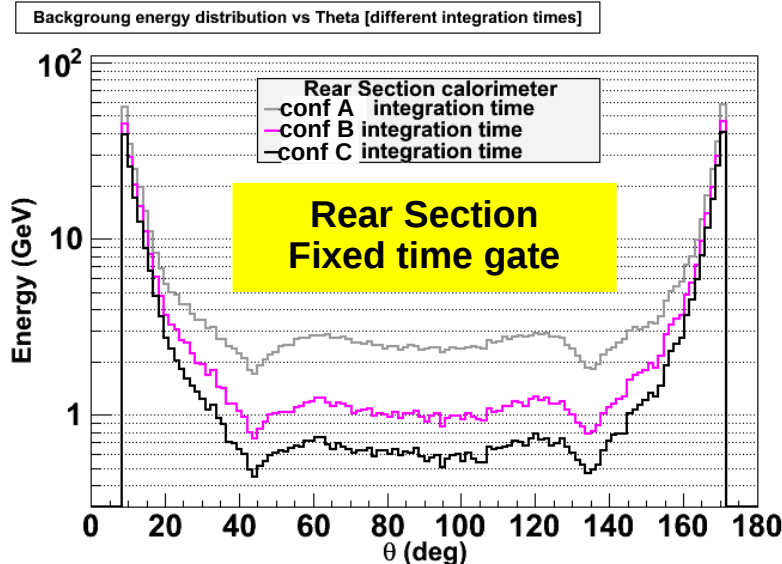
## Integration time gate for each section

	Front Section		Rear Section	
	Scint	Cer	Scint	Cer
<b>conf A</b>	100 ns	100 ns	100 ns	100 ns
<b>conf B</b>	20 ns	15 ns	25 ns	25 ns
<b>conf C</b>	15 ns	6 ns	22 ns	22 ns

- In **conf B** 95% of the signal is integrated
- In **conf C** 90% of the signal is integrated

# Angular distribution of background for different integration times

1 entry = <1 cell>

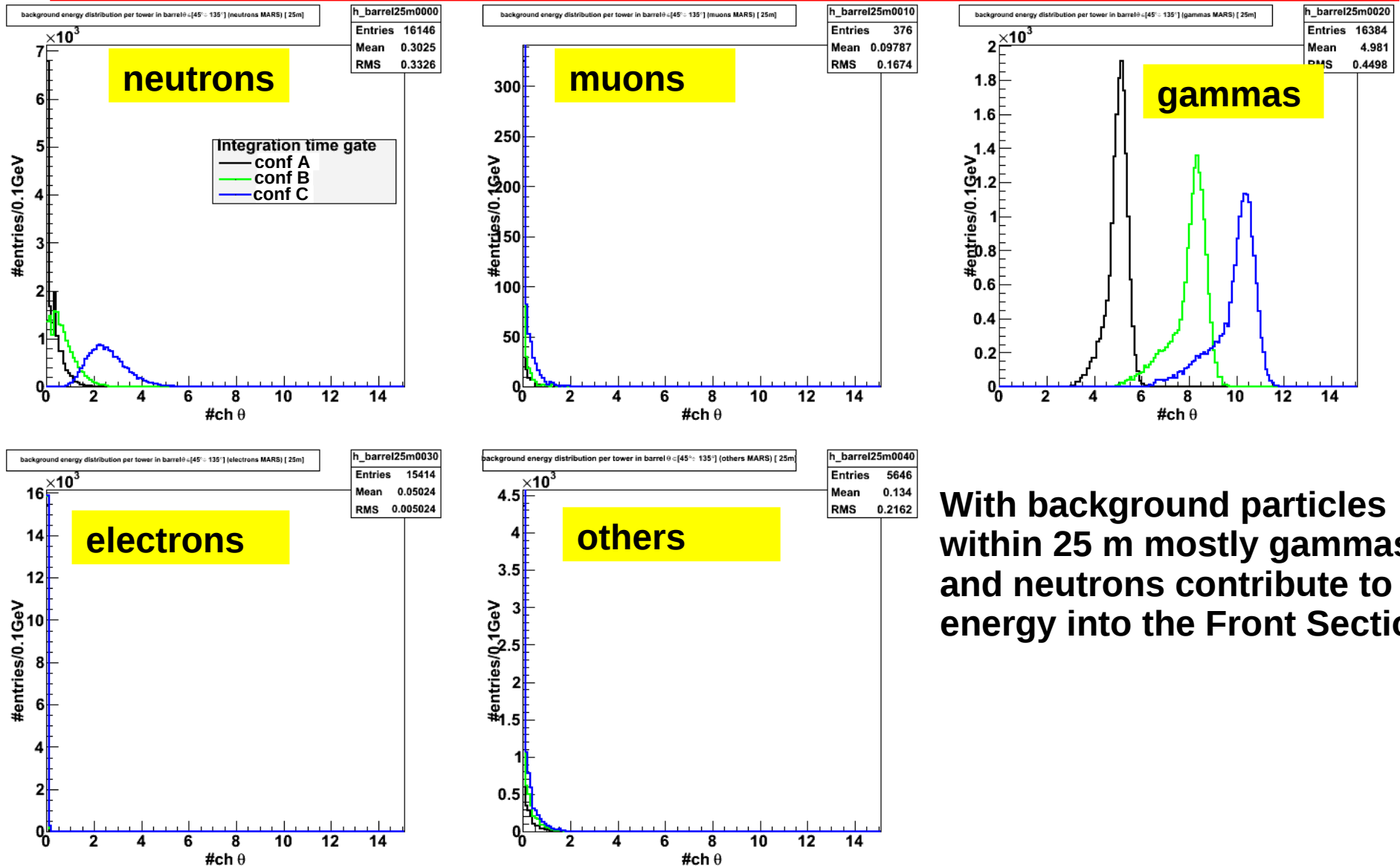


The background reduction is higher going from 25 to 15 ns than going from 100 to 25 ns  
Note: the background energy peak is between 20 – 35 ns



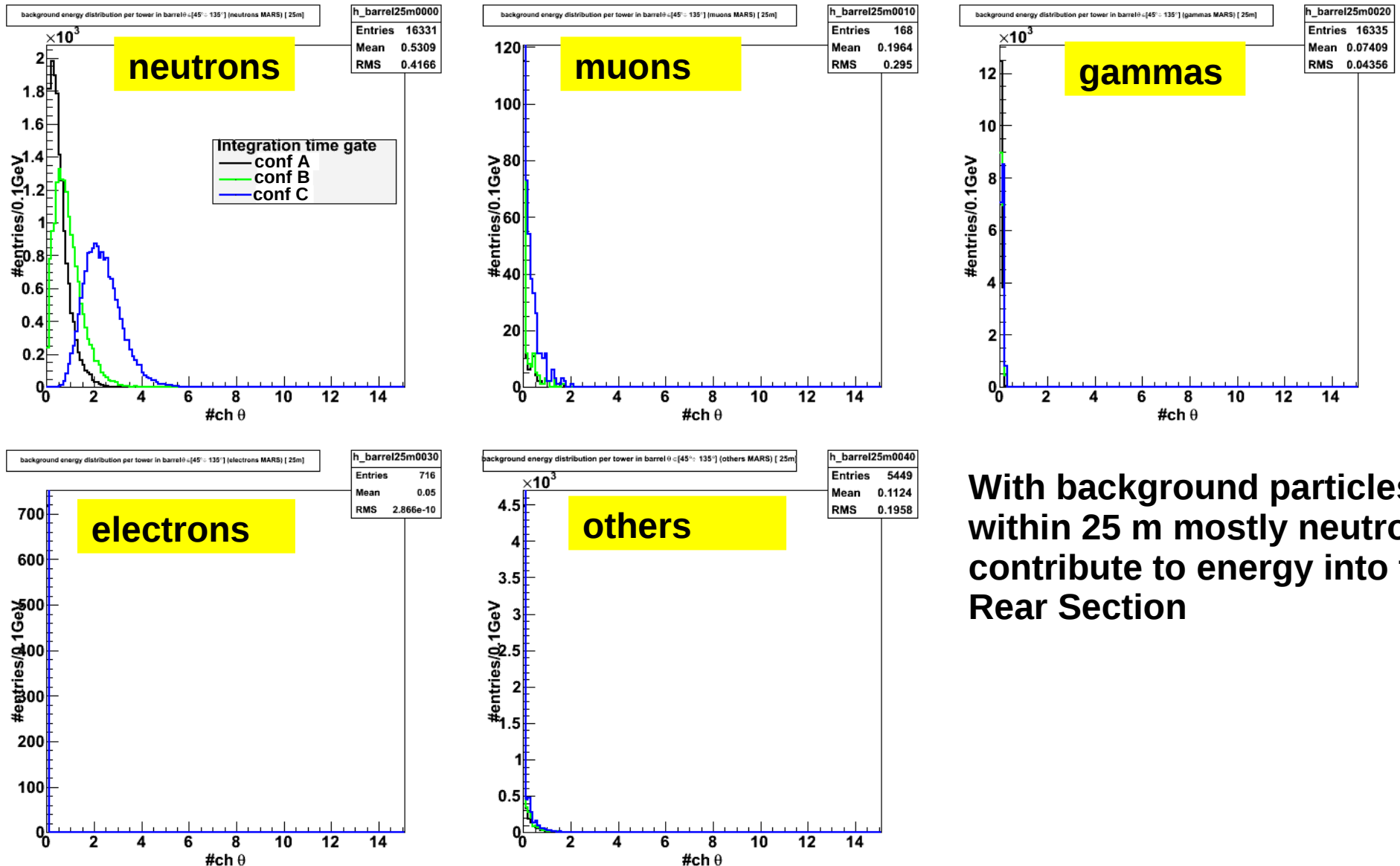
# Energy distribution of the background per tower in barrel section for different species using different time gate

# Background energy distribution per tower in barrel Calorimeter **Front Section**; different integration times



With background particles within 25 m mostly gammas and neutrons contribute to energy into the Front Section

# Background energy distribution per tower in barrel Calorimeter **Rear Section**; different integration times

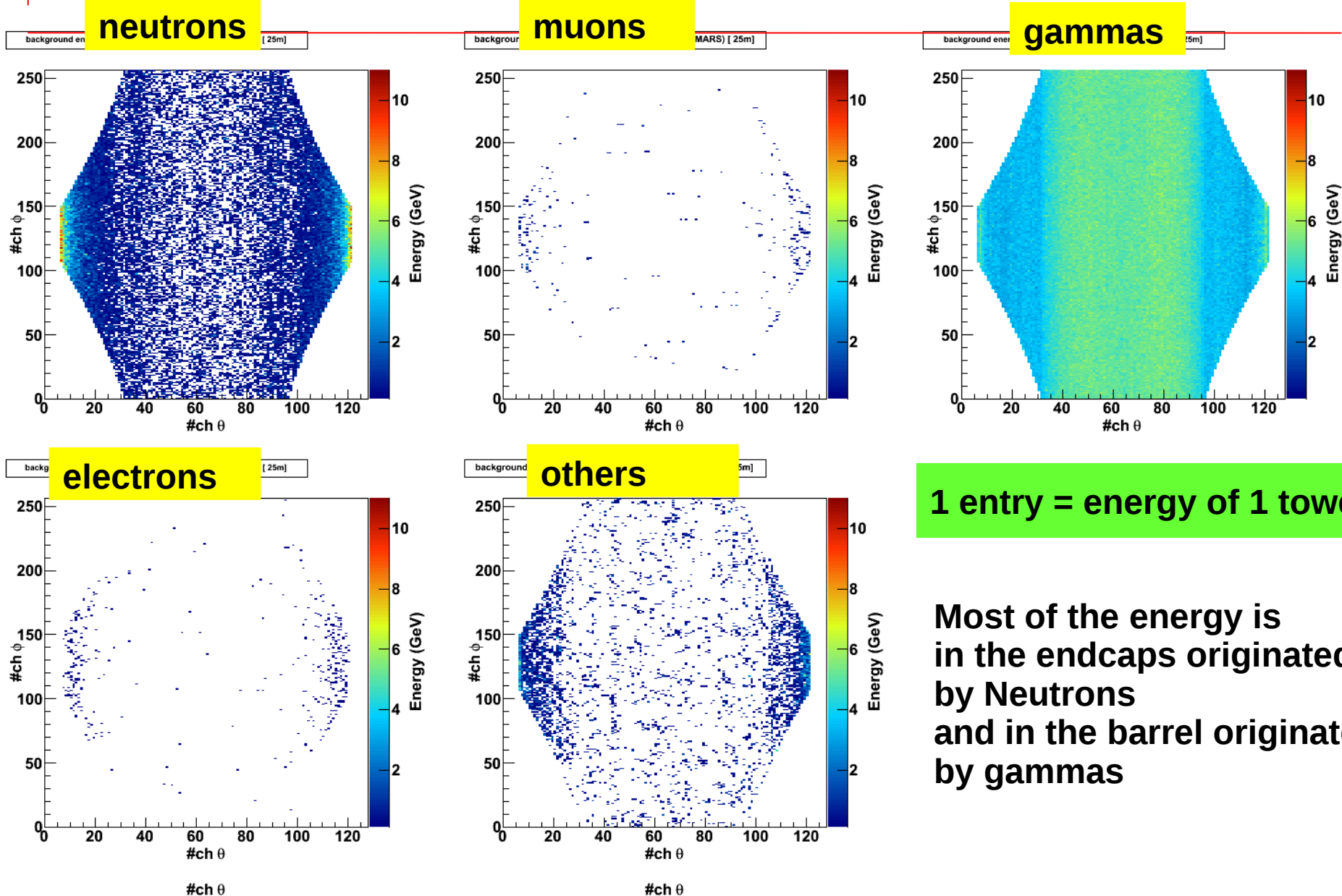


With background particles within 25 m mostly neutrons contribute to energy into the Rear Section

Look at the energy distribution  
of the background per tower  
for different species

# Background energy distribution per tower

## Calorimeter **Front Section** Integration time gate **conf C**

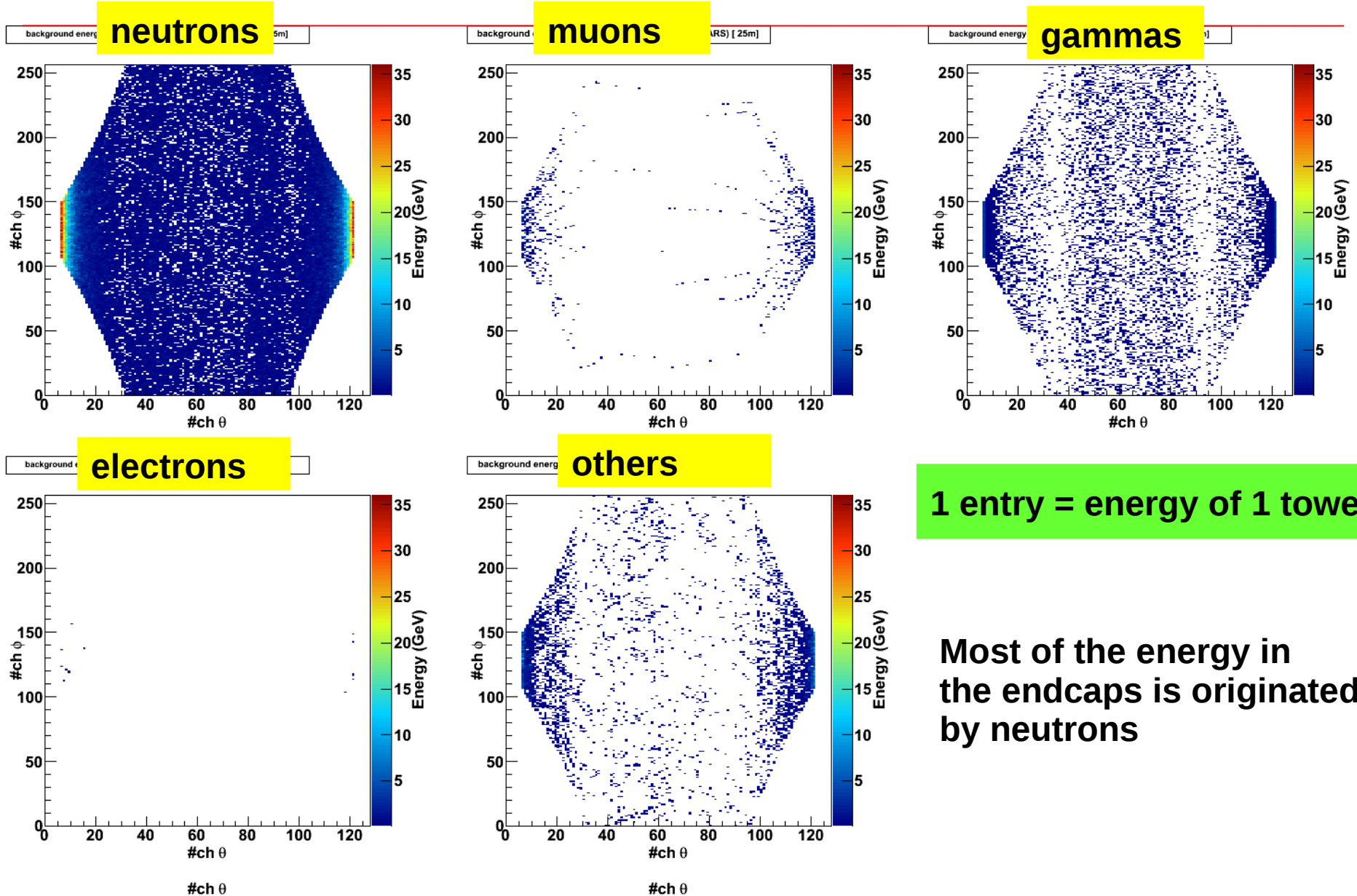


1 entry = energy of 1 tower

Most of the energy is  
in the endcaps originated  
by Neutrons  
and in the barrel originated  
by gammas

# Background energy distribution per tower

## Calorimeter **Rear Section** Integration time gate **conf C**

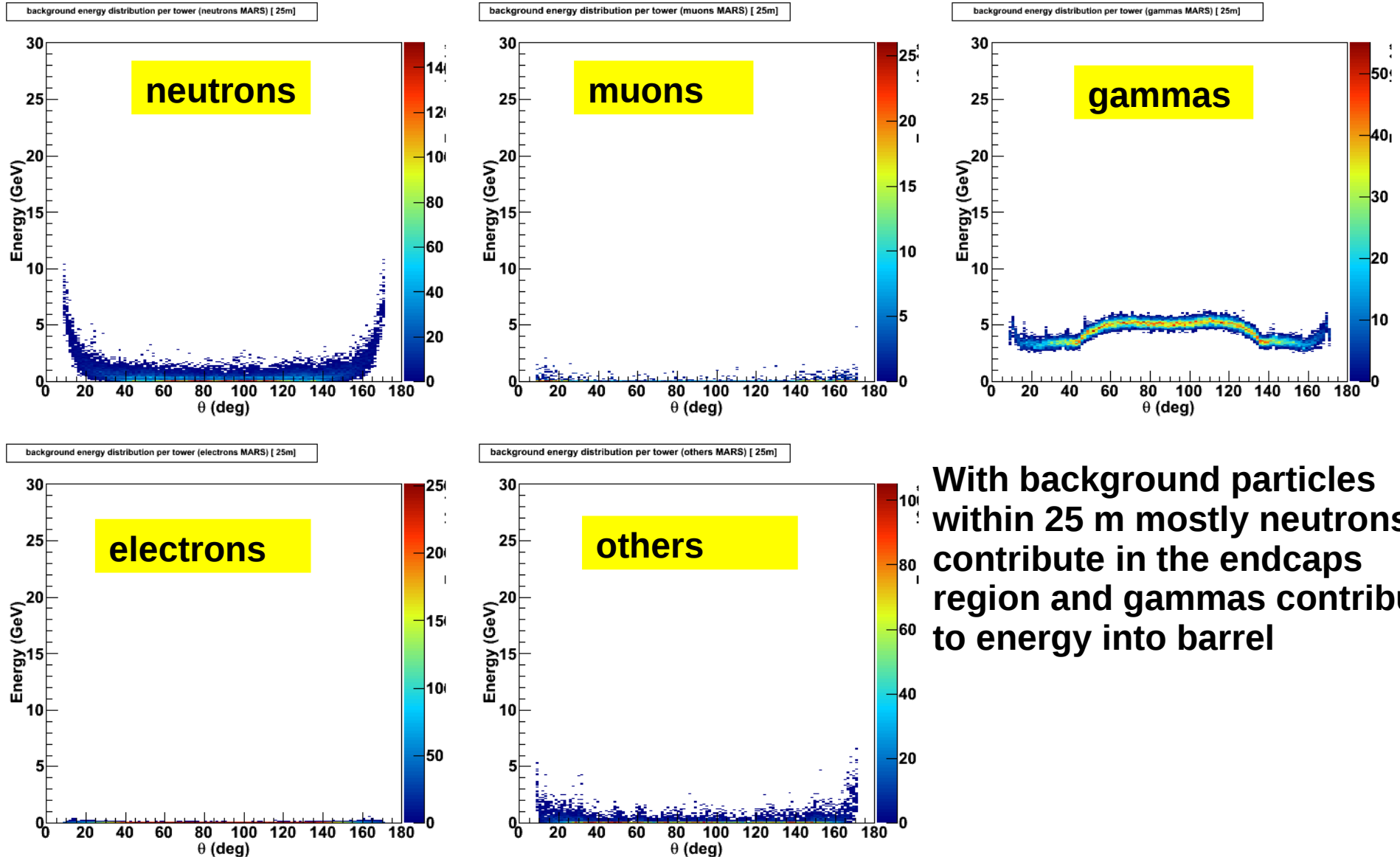


1 entry = energy of 1 tower

Most of the energy in the endcaps is originated by neutrons

# Energy distribution of the background per tower vs theta for different species

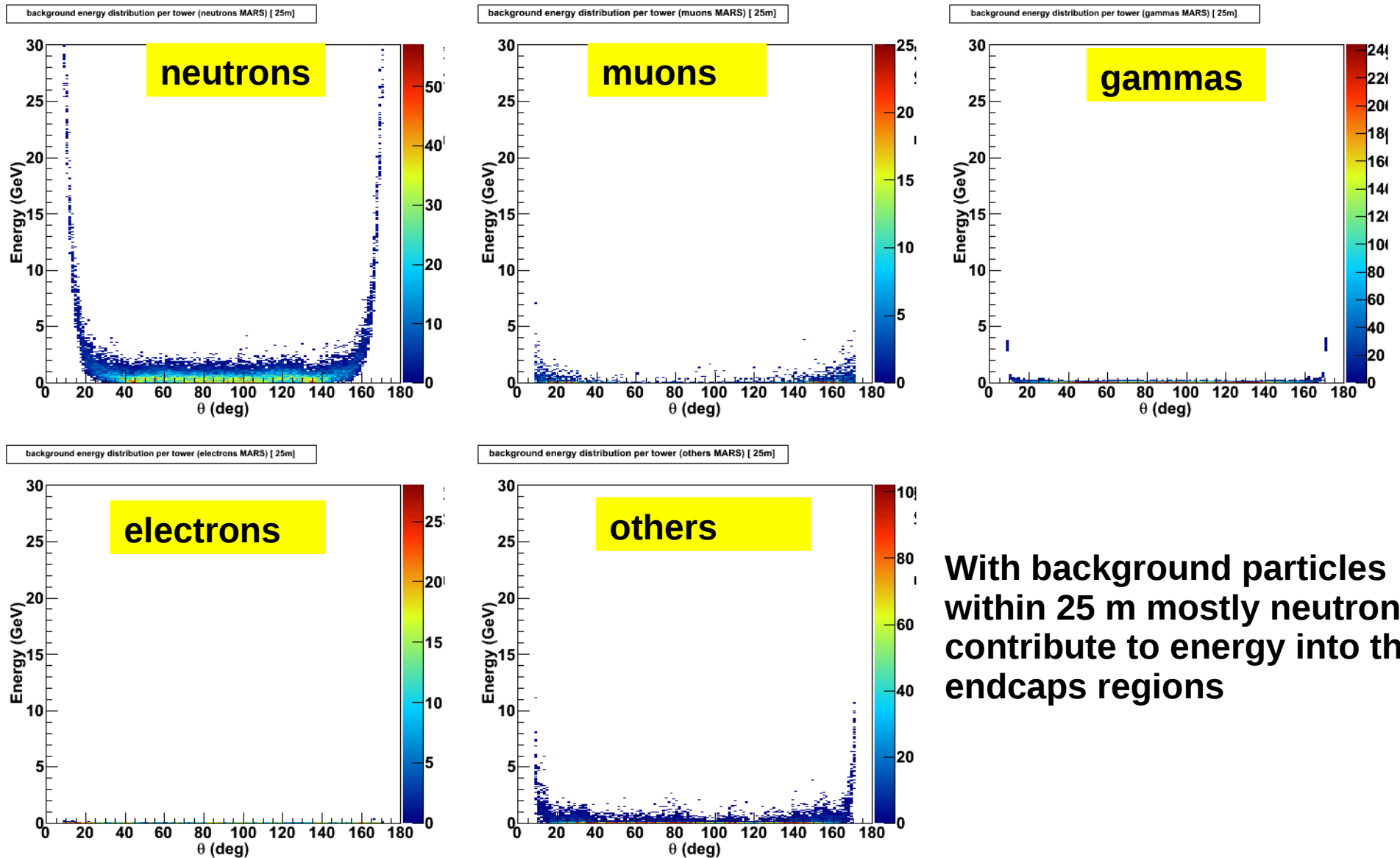
# Background energy distribution per tower vs theta. Calorimeter **Front Section**; Integration time gate **conf C**



With background particles within 25 m mostly neutrons contribute in the endcaps region and gammas contribute to energy into barrel



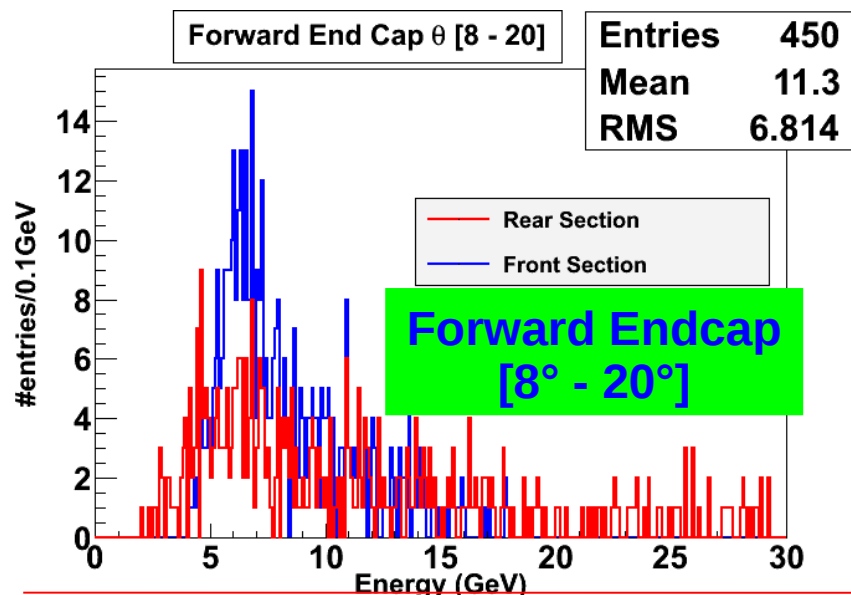
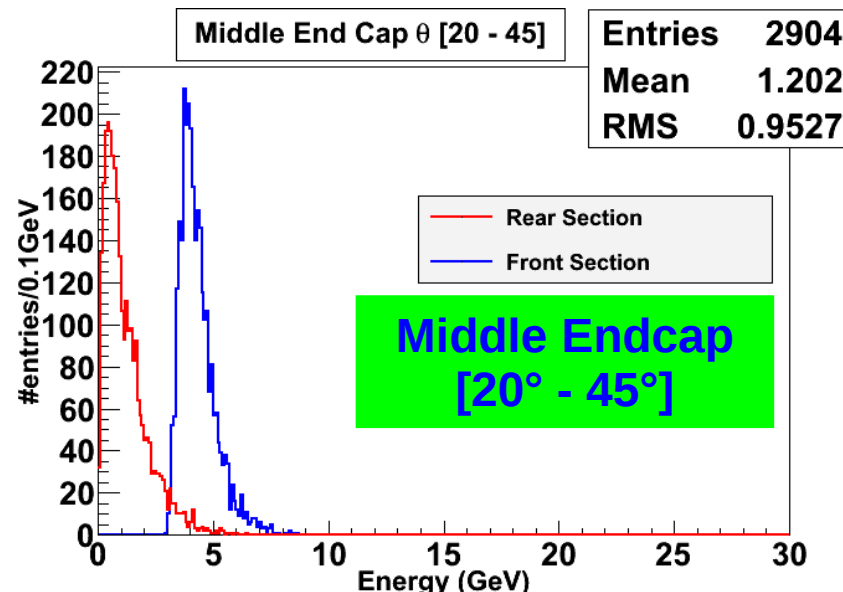
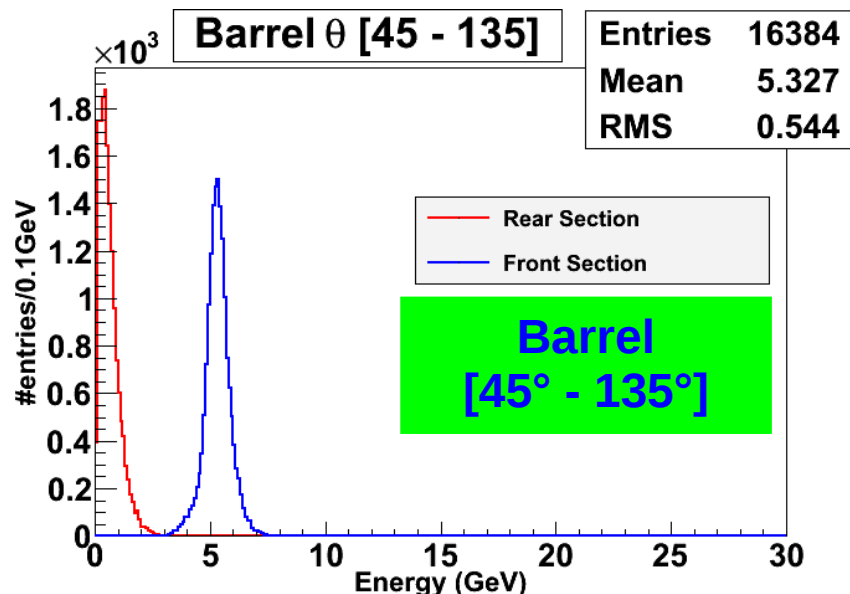
# Background energy distribution per tower vs theta. Calorimeter **Rear Section**; Integration time gate **conf C**



With background particles within 25 m mostly neutrons contribute to energy into the endcaps regions

Total energy distribution  
of the background per tower  
In barrel section  $[45^\circ - 135^\circ]$   
and endcap sections  $[20^\circ - 45^\circ]$   
And  $[8^\circ - 20^\circ]$

# Background energy distribution per tower in **Front and Rear Section** Integration time **conf C**



Background energy fluctuation		
Energy (GeV)	Front	Rear
Barrel	5.33±0.54	0.63±0.43
Mid ECap	4.33±0.79	1.20±0.95
Forward ECap	8.31±2.94	11.3±6.8

# Physics and background at a Muon Collider: some comment

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- Jets develop in 16 – 25 towers; mean energy 150 GeV
- Background in barrel Rear Section:  
mean energy 0.6 GeV RMS 0.4 GeV  
Jet energy fluctuation after background pedestal  
cut 1.5 – 2 GeV
- Background in endcap  $> 20^\circ$  Rear Section  
mean energy 4 GeV RMS 0.8 GeV  
Jet energy fluctuation after background pedestal  
cut 3 – 4 GeV
- Background in endcap  $< 20^\circ$  Rear Section  
mean energy 11 GeV RMS 7 GeV  
Jet energy fluctuation after background pedestal  
cut 28 – 35 GeV

# Merging issues to be addressed

- Merging is done from SDigits to Digits (inherited by AliRoot)
- For Alice this works fine. In high multiplicity event PbPb ions they have  $\sim 10^4$  particles per event
- In a MuonCollider MARS background event there are  $\sim 10^8$  particles per event
- To be able to simulate a full MuonCollider background event I split it in  $\sim 2 \times 10^3$  subsections
- Using the classic merge technique is time expensive
- Different approach can be used: apply filter at hit level, it is accurate and very efficient.

# Conclusion

- **Accurate study about MuonCollider background have been presented**
- **Mars to ILCroot interface is excellent**
- **The machinery for full simulations is in place and working smoothly**
- **Below 20° Physics is affected considerably**
- **More work is need to implement a more efficient merging of background and Physics**

Present detector configuration is OK  
More optimization work is needed to reduce the background to a comfortable level

# Backup slides

# Required Computing Resources

**Time and disk space needed to simulate 1 Muon Collider background event at hits level.**

- **Particles with weight 1;**
  - **1 CPU  $\leftrightarrow$  2400 h**
  - **200 Gb disk space**
- **Disk space and CPU time can be reduced applying filter at hit level.**



